

UC RIVERSIDE
UNIVERSITY OF CALIFORNIA



Why do I need

to know math?



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University of California,
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Mathematics as a Way of Knowing

In our endeavor to understand reality we are like a man trying to understand the mechanism of a closed watch. He sees the face and the moving hands, even hears its ticking, but he has no way of opening the case. If he is ingenious, he may form some picture of a mechanism which could be responsible for all the things he observes, but he may never be quite sure his picture is the only one which could explain his observations.



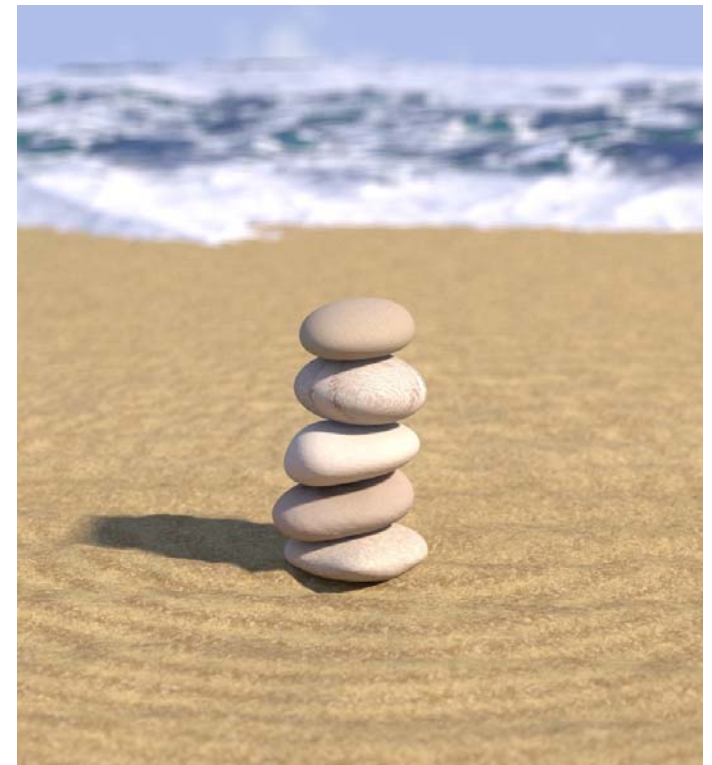
Einstein and Infeld
The Evolution of Physics

Mathematics as an Art of Knowing

At the leading edge of experience in philosophy, science and feeling there is inevitably a groping for language to translate the insecure novelty of noticing and understanding into a precision of meaning and imagery.

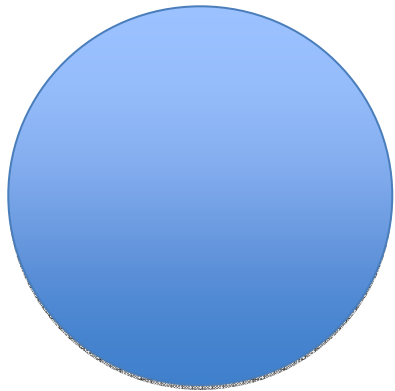
Frank Oppenheimer

- Math is the language to describe Nature
- Math allows to see the unseeable
- Math has predictive power

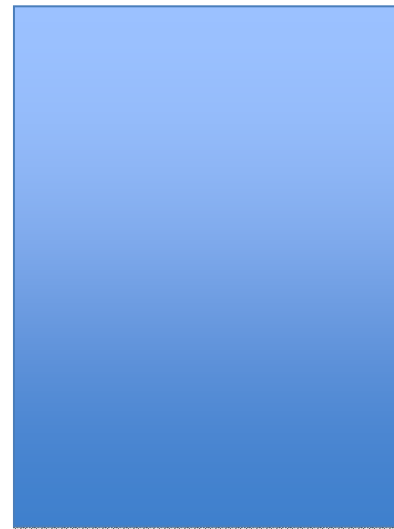


A Game of Shadows

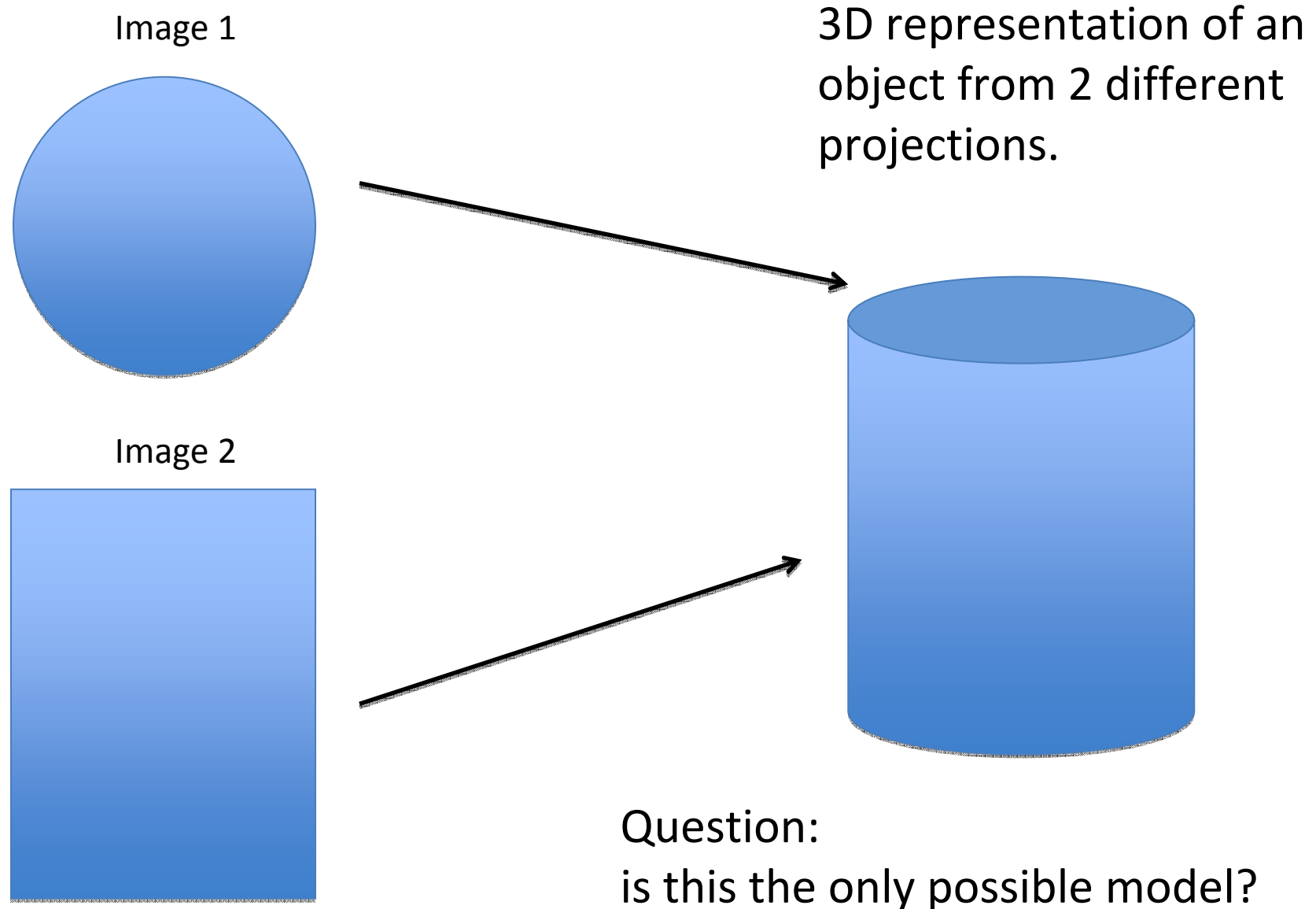
NASA Image 1 – 8am



NASA Image 2 – 12pm

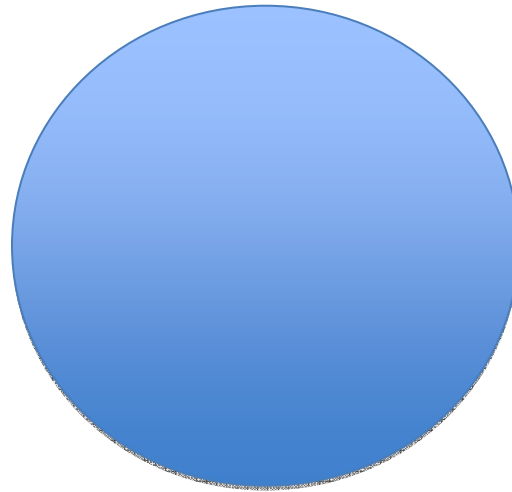


A Game of Shadows



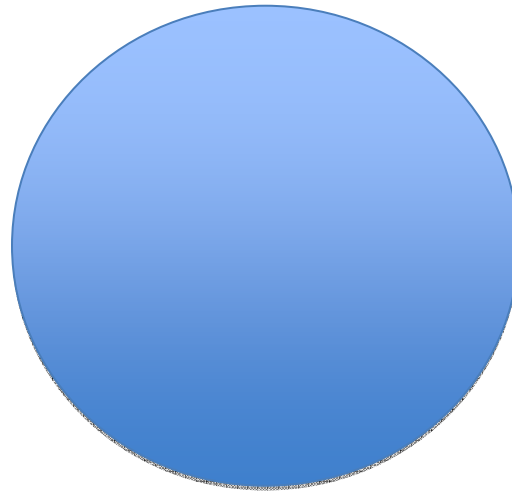
Let's build a cow...

An engineer, a psychologist and a physicist are called in as consultants to a dairy farm. They are tasked to make suggestions to increase milk production...



Let's build a cow...

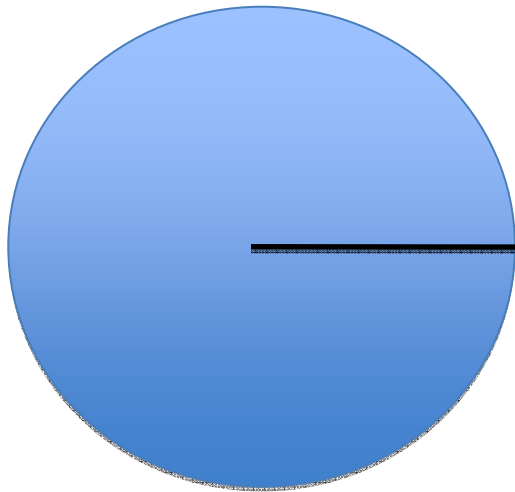
An engineer, a psychologist and a physicist are called in as consultants to a dairy farm. They are tasked to make suggestions to increase milk production...



Start to think simply about the world
by eliminating irrelevant details.

Let's build a cow

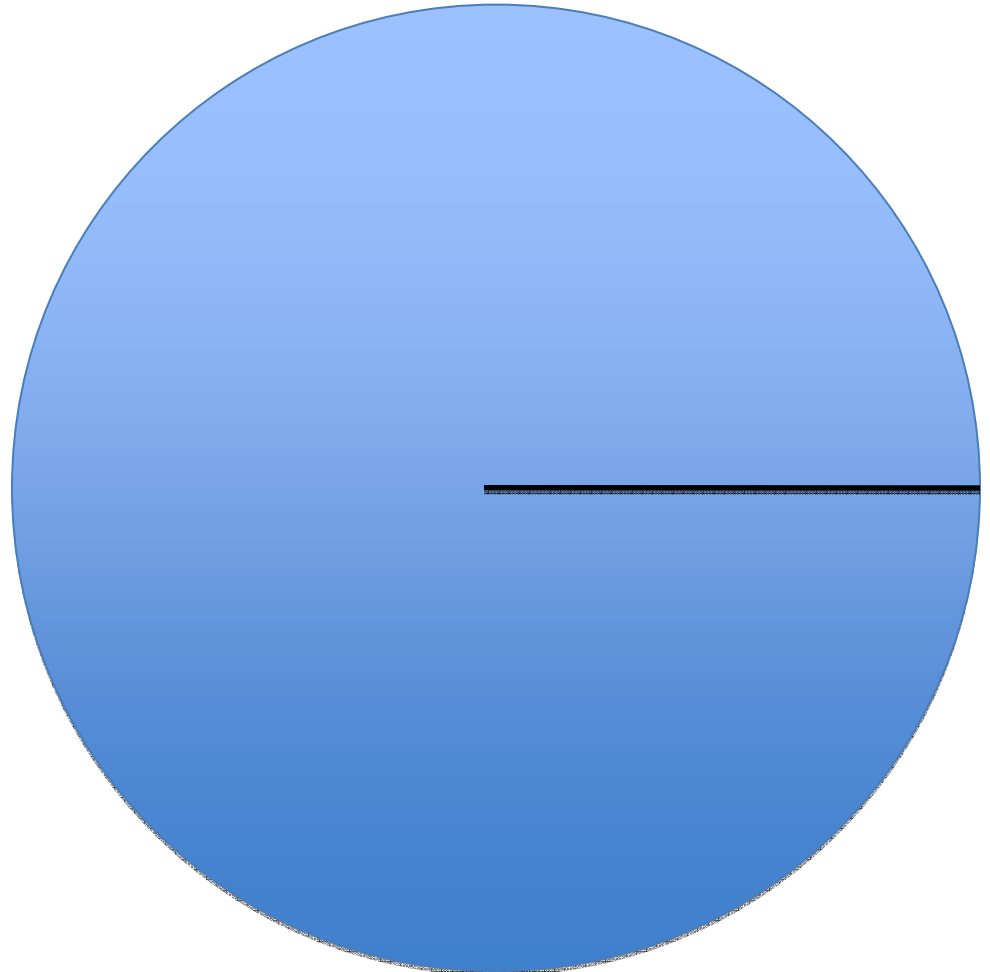
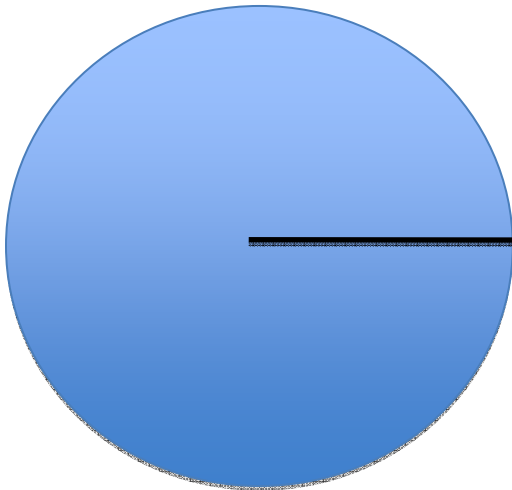
- At the core of the ability to make scientific models is the ability to reason in terms of proportions
- Scale-up, scale-down, fractions!



My cow is completely determined
by the radius of the sphere: r

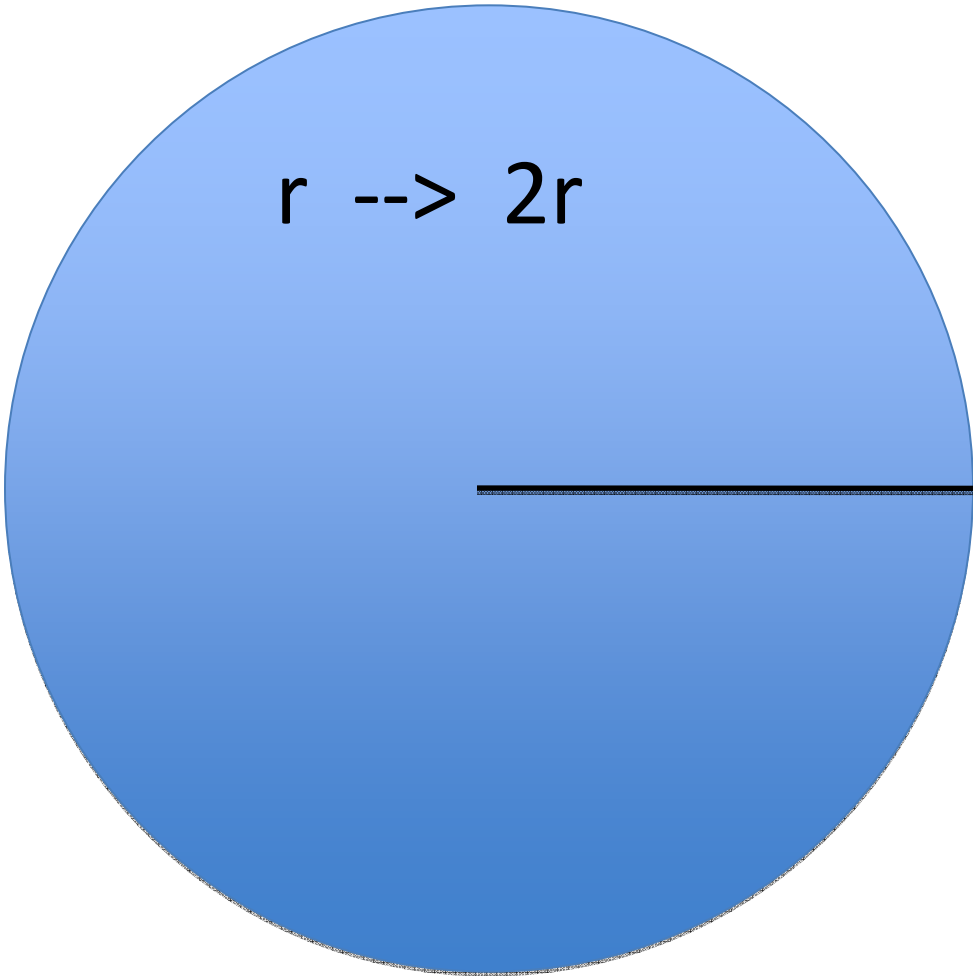
Let's build a supercow

$r \rightarrow 2r$



What does really mean that the supercow is twice as big as a regular cow?

About my supercow



$r \rightarrow 2r$

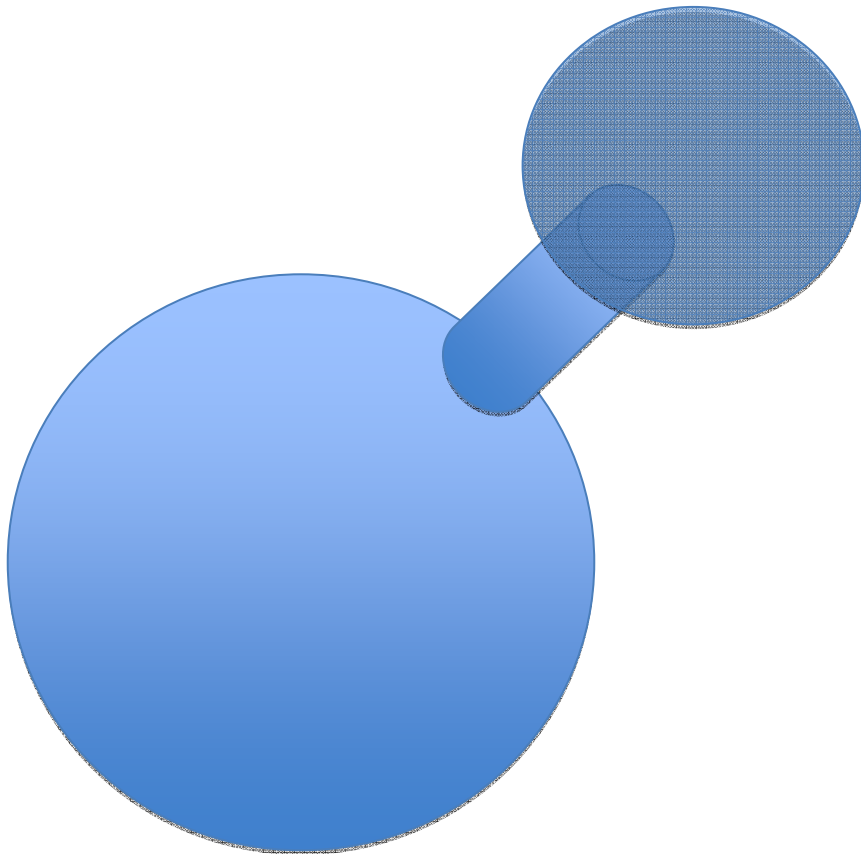
The supercow is:

- 8 times more heavy (volume)
- 4 times more skin (surface area)

What are the implications?



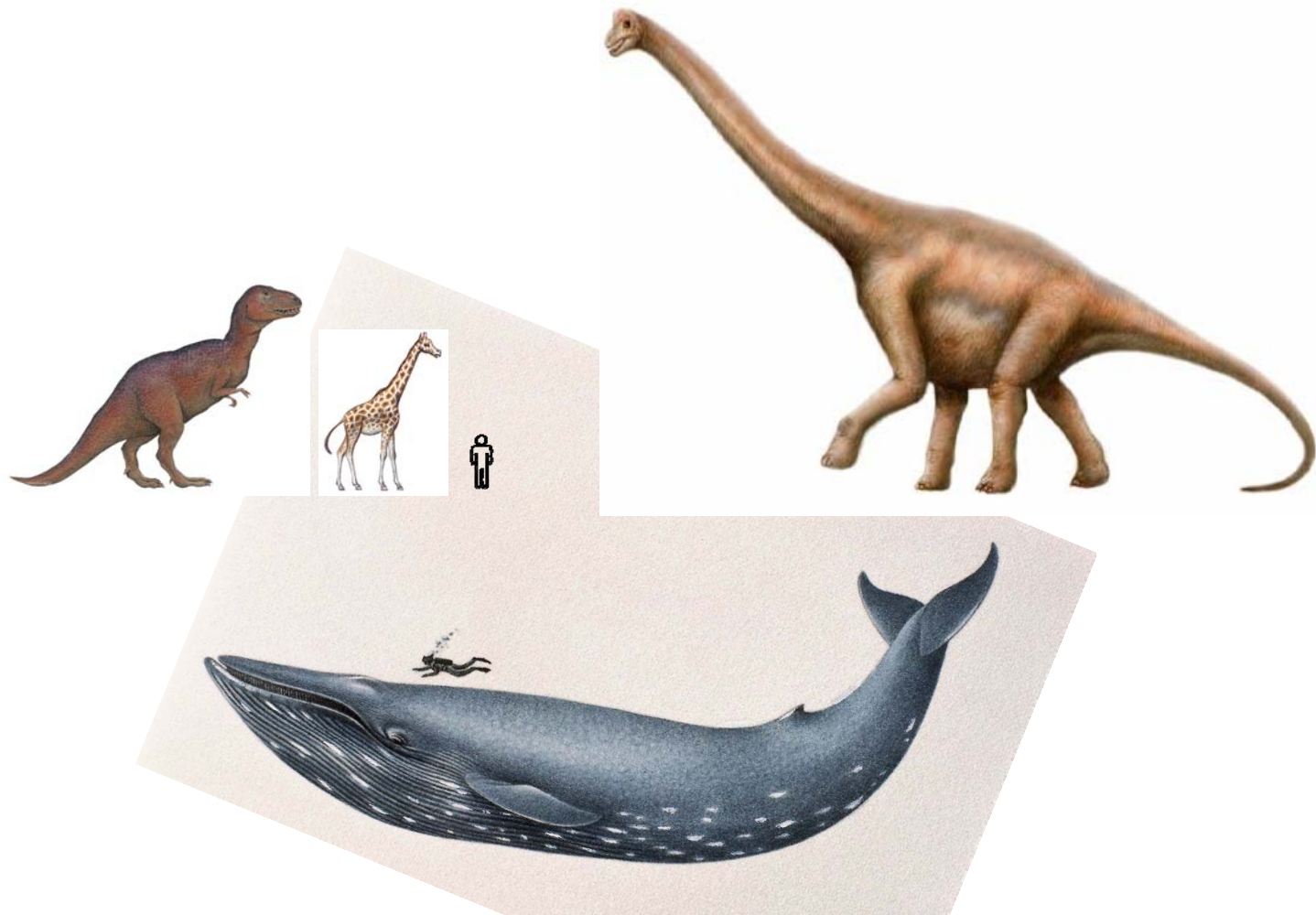
An improved cow model...



- New element in the model: the cow's neck
- The strength of the neck is proportional to its cross section
- The neck of my supercow is only 4 times stronger (surface area) to hold up a head that is 8 times heavier!
- The neck is only 50% as effective in supporting the head.

Lesson Learned from Building a Cow

- If the only tool you have is a hammer, you tend to treat everything as if it were a nail.*



NASA Shuttle Launch (modeling)

This is a modeling exercise:

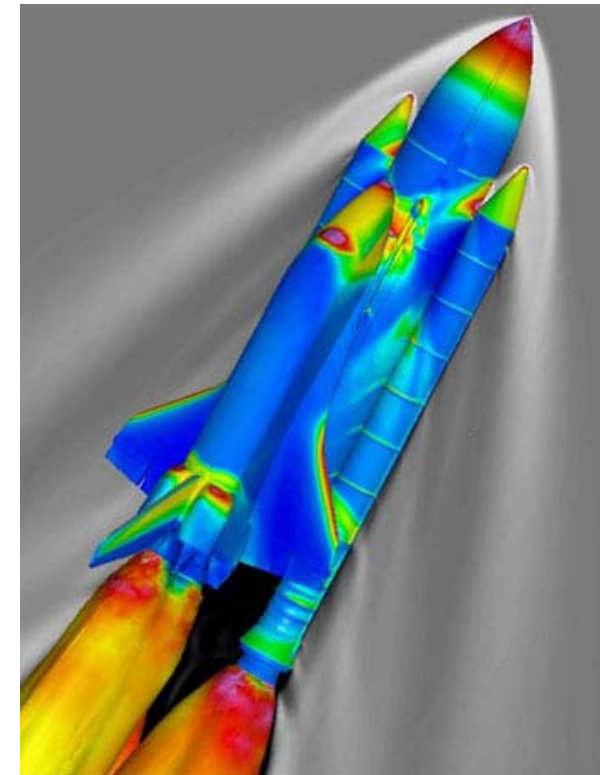
- Start simple (but we know it is a complex problem)
- Consider only what seems relevant
- Think of the physics involved

Key point:

Trying to understand things exactly,
we often miss the important fundamentals
and get hung up on side secondary issues.



NASA Space Shuttle Mission Profile



Tesla Car (when smaller is better)

- Code name: Dark Star
- Maker: Tesla Motors, Menlo Park, CA
- Engine: 3-phase electric motor (Li-ion battery technology)
- Performance: 0-60mph in 4 sec
- Max speed: 125mph
- Efficiency: 244 miles in a single battery charge
- Base price: \$100k (but you get tax incentives!)



The engineering secret:

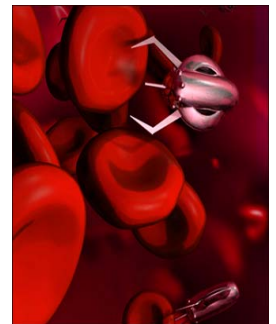
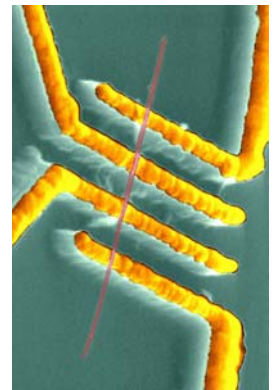
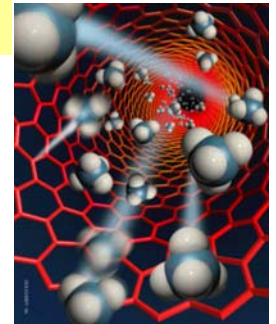
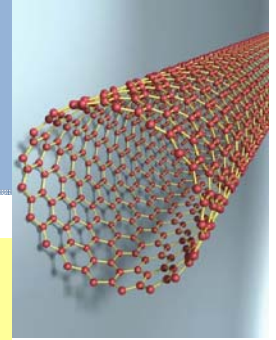
- 6800 Li-ion battery cells (just a bit smaller than regular AA battery)
- total battery pack ~ 5-10% of total car weight

Nanotechnology

1 nanometer = 1/100,000,000 of a meter
(one billionth of a meter, or 10^{-9} meters, the size of a carbon atom)

Nanotechnology is ...

- An emerging, interdisciplinary science involving **mathematics**, physics, chemistry, biology, engineering, etc.;
- A way to study, control and manipulate matter at the atomic scale (nano-scale);
- An *enabling technology* with impacts on electronics, computing, medicine, energy, environment, and much more!



On the cutting-edge

What does it take to work at the nanoscale.

- Materials

- 1 strip of paper 11" x 1"
- Scissors

- Questions

- How many cuts can you make?
- How many cuts would you need to make to reach the size of an atom (1nm) ?

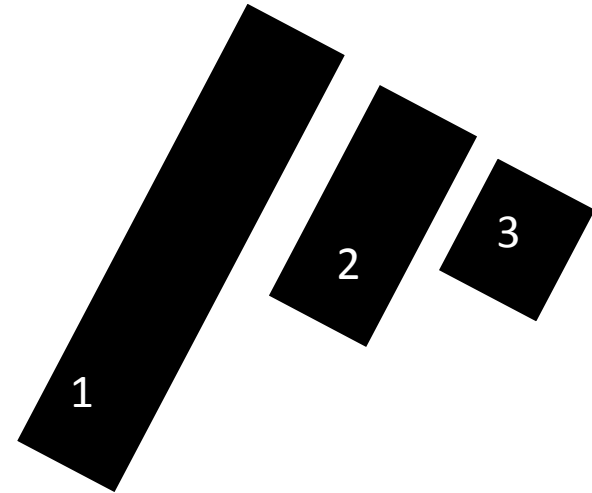


Table for data organization

Cut #	Fraction of original strip	Power Rule	Length (cm)	Comparison
0	1		28	
1				
2				
3				
4				
5				
6				

Table for data organization

Cut #	Fraction of original strip	Power Rule	Length (cm)	Comparison
0	1	$1/2^0$	28	My arm
1	$1/2$	$1/2^1$	14	My hand
2	$1/4$	$1/2^2$	7	Index finger
3	$1/8$	$1/2^3$	3.5	
4	$1/16$	$1/2^4$	1.75	
8	$1/256$	$1/2^8$	0.11	

Challenge #3: On the Cutting-edge

How many cuts are needed to reach 1nm?

What I know: for 8 cuts I have

$$0.109 \text{ cm} = 28 \text{ cm} \times 1/2^8$$

What I need to know: after x cuts I have 1nm

$$10^{-7} \text{ cm} = 28 \text{ cm} \times 1/2^x$$

Need to solve for x: $1/2^x = 10^{-7}/28$

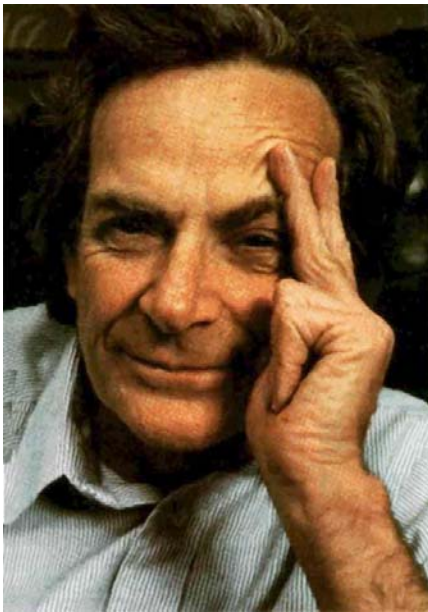
You can solve this in 2 ways:

- exactly (using log and calculator) $x = 28$
- or by approximations ($28 \approx 32 = 2^5$ and $5 \approx 4 = 2^2 \rightarrow 10^7 = 2^{21}$ or $5 \approx 8 = 2^3 \rightarrow 10^7 = 2^{28}$) $x = 26$; $x = 33$

How did we get here?

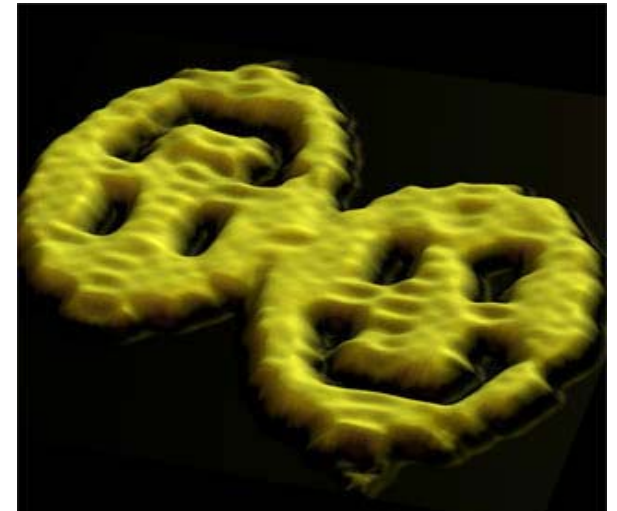
Origin of Nanoscience

- New Tools! As tools change, what we can see and do changes.



First theoretical introduction by
Richard Feynman
"There's Plenty of Room at the Bottom"
American Physical Society, 1959

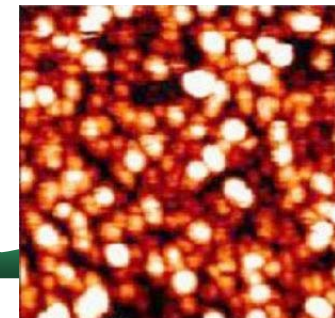
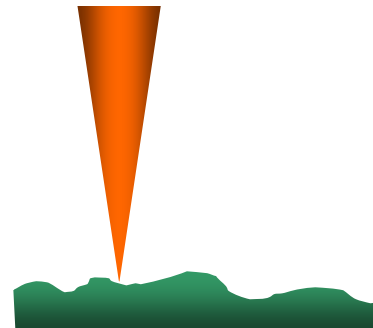
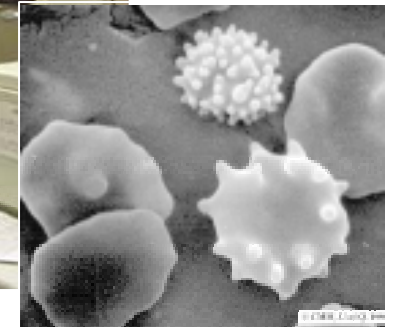
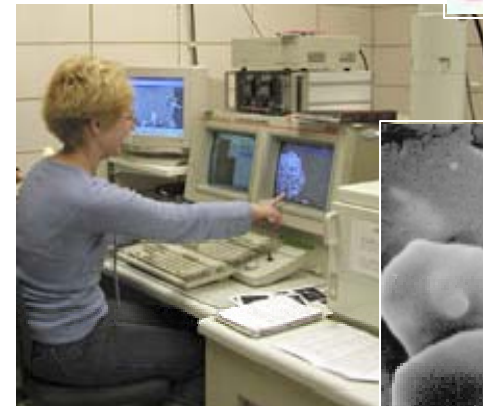
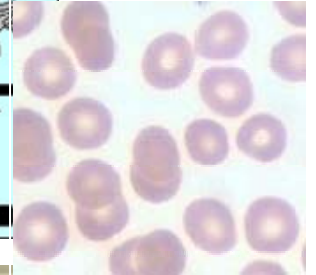
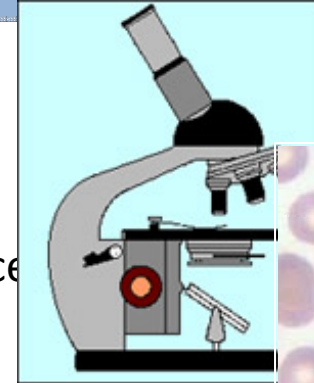
The key is to make use of the
unique properties which arise
because of the nanoscale.



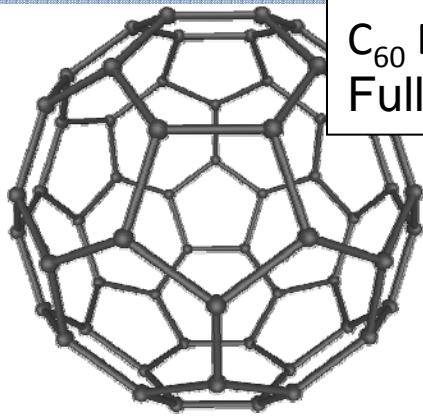
DNA Origami by Paul Rothemund

How to See Small Things

- The **naked eye** can see to about $20\mu\text{m}$
- **Light microscopes** let us see to about $1\mu\text{m}$ (bounce **light** off of surfaces to create images)
- Scanning electron microscopes (1930s) let us see objects as small as 10 nm (bounce electrons off of surfaces to create images)
- Scanning tunneling microscope (1980) and atomic force microscope (1986) let us see and interact with the atomic structure (use the atom-to-atom interaction to map the surface)

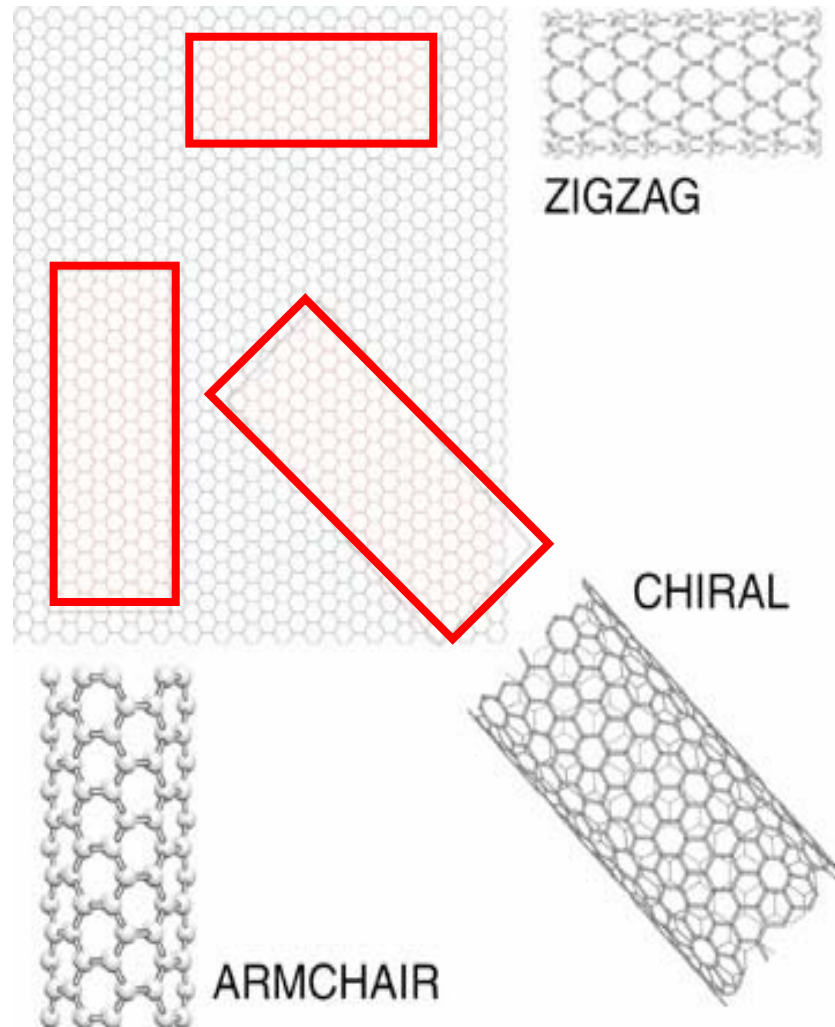


What did we see? New things!



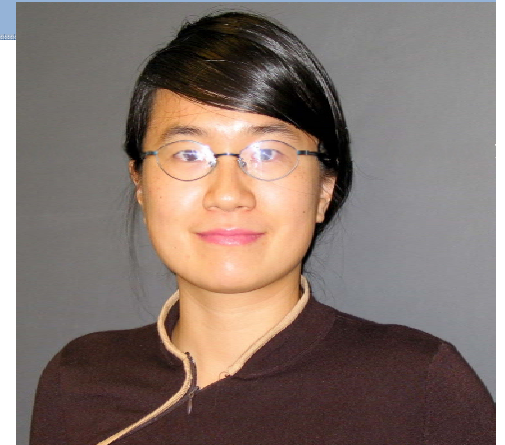
C_{60} Buckyball or Fullerene

Graphene and Nanotubes



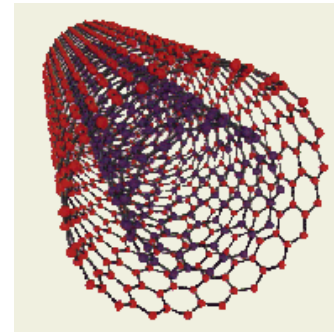
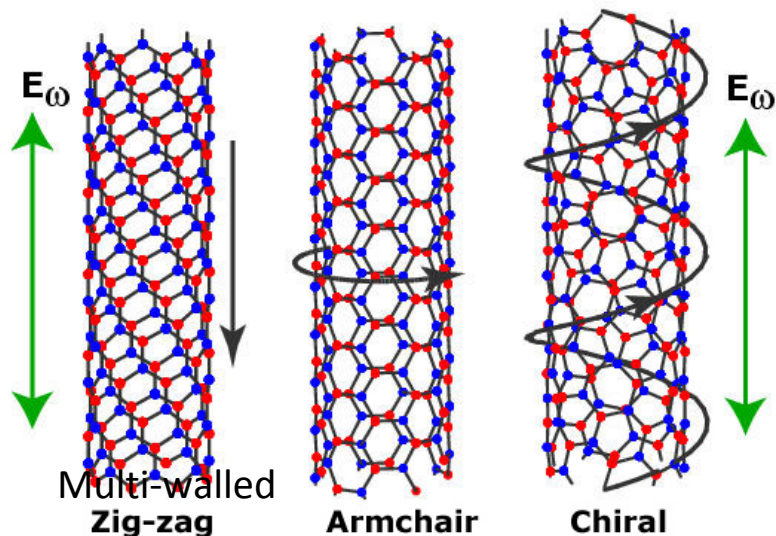
Fuller's American Pavillion,
Monreal Expo '67

Electrical Properties: Conductivity of Nanotubes



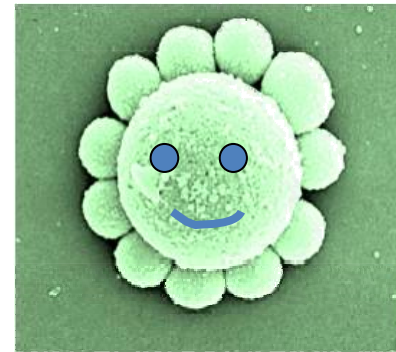
Jeanie Lau

- Because the mass of nanoscale objects is so small, gravity becomes negligible
- Nanotubes are long, thin cylinders of carbon
 - They are 100 times stronger than steel, very flexible, and have unique electrical properties
- Their electrical properties change with diameter, “twist”, and number of walls
 - They can be either conducting or semi-conducting



Size-Dependent Properties of Materials

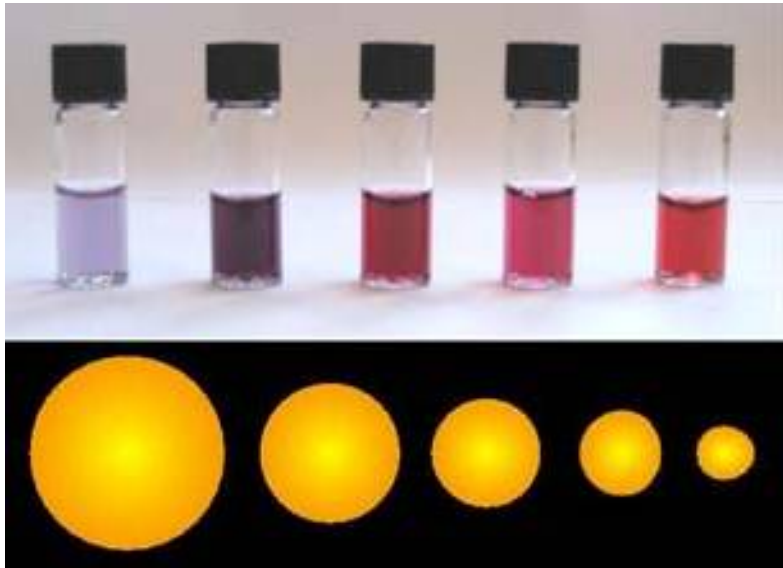
- Types of properties that describe how materials act under certain conditions:
 - Optical (e.g. color, transparency)
 - Electrical (e.g. conductivity)
 - Physical (e.g. hardness, melting point)
 - Chemical (e.g. reactivity, reaction rates)
- At the nanoscale, properties change because different forces dominate at different scales.
- If you are a nanoparticle you are:
 - *Sticky* (intermolecular forces)
 - *Shaky* (thermal energy)
 - *Bumpy* (quantum effects)
 - *Gravity doesn't matter* (really weak)



Optical Properties: Color of Gold

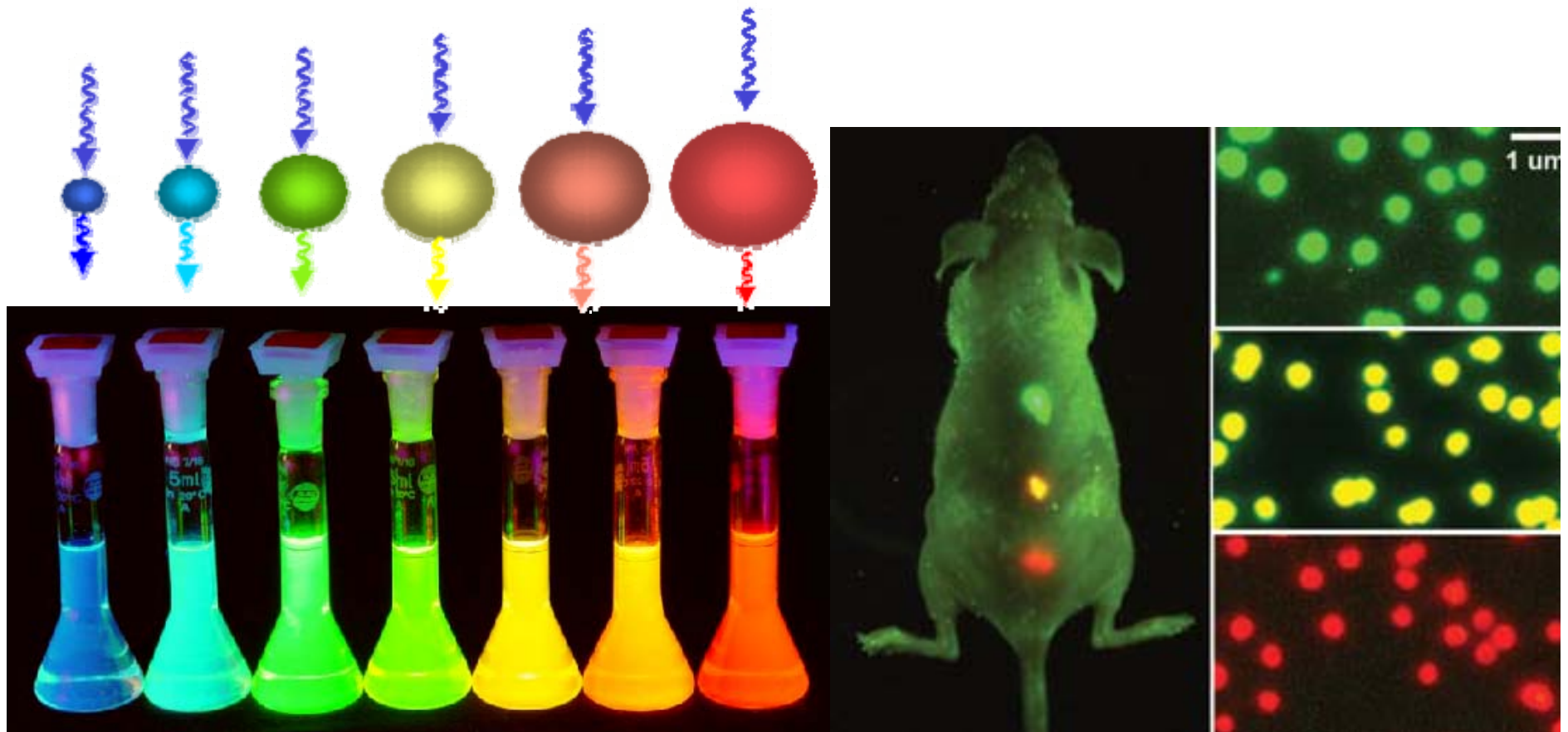
Nanosized gold appears red in color

- Nano particles are so small that electrons are not free to move about as in bulk gold
- Because the movement is restricted, the particles react differently with light

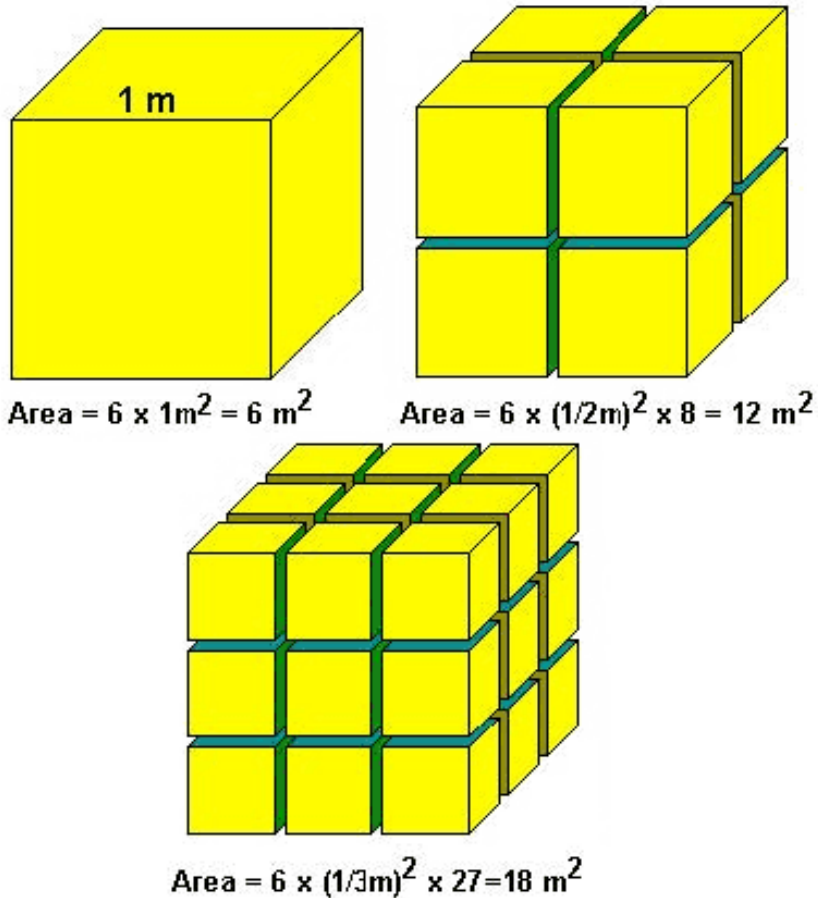


Optical Property of Quantum Dots

Quantum dots (metal oxide particles) glow in UV light and their color depends on their size



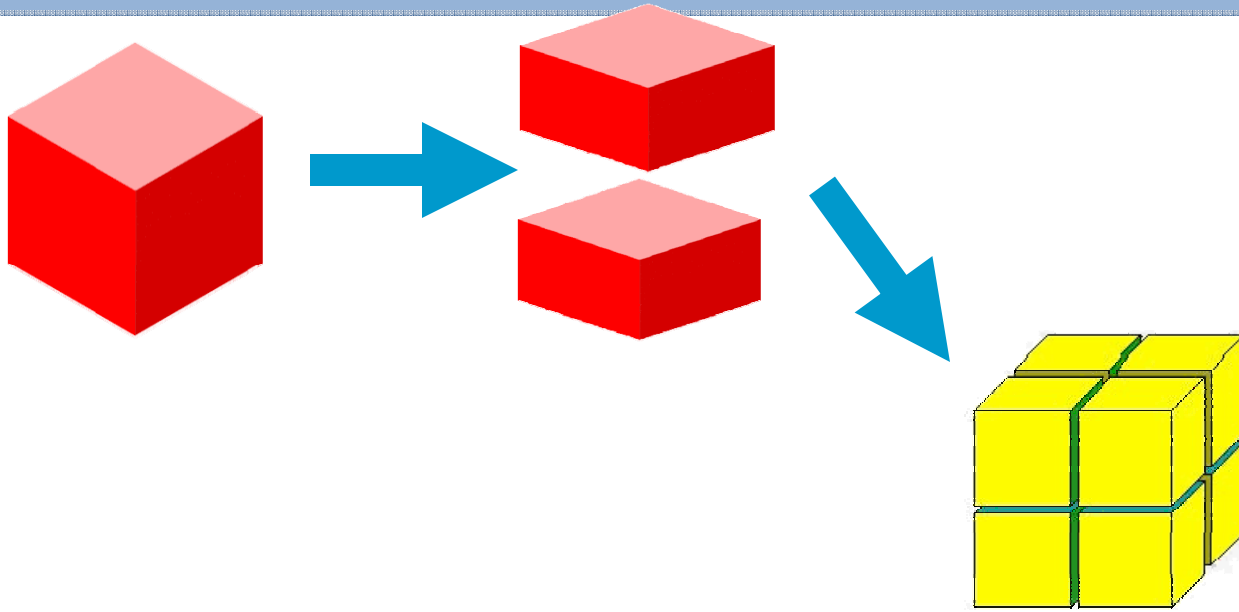
It's all at the surface...



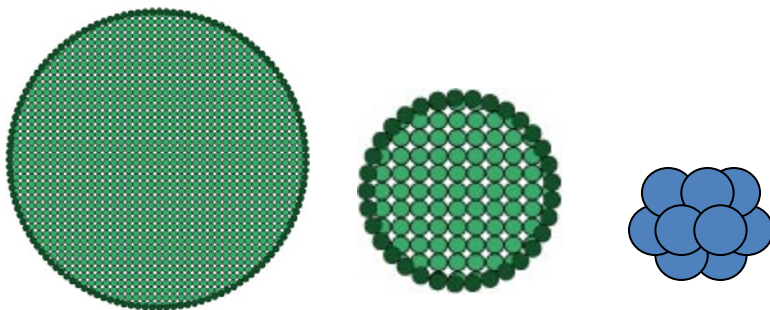
Nanomaterials have a large surface area for a given volume (increase of surface to volume ratio)

	At the macroscale	At the nanoscale
The majority of the atoms are...	...almost all on the inside of the object	...split between the inside and the surface of the object

Technology: It's all at the surface...

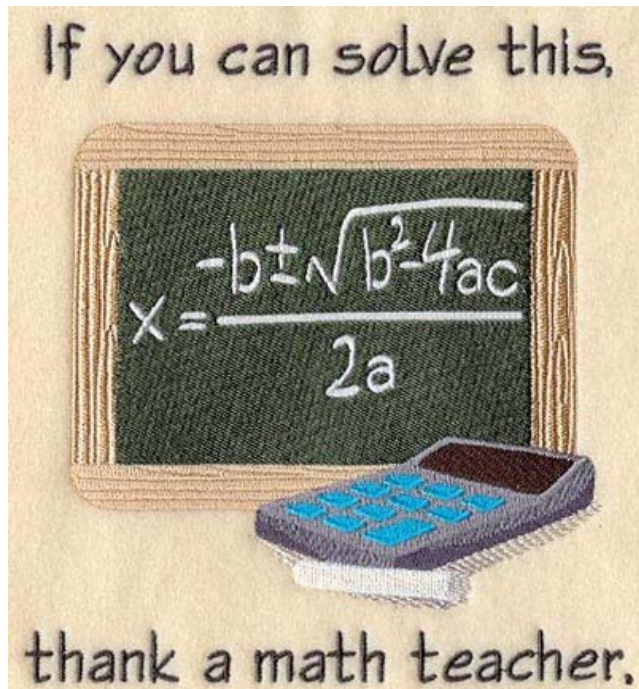


Sharon Walker

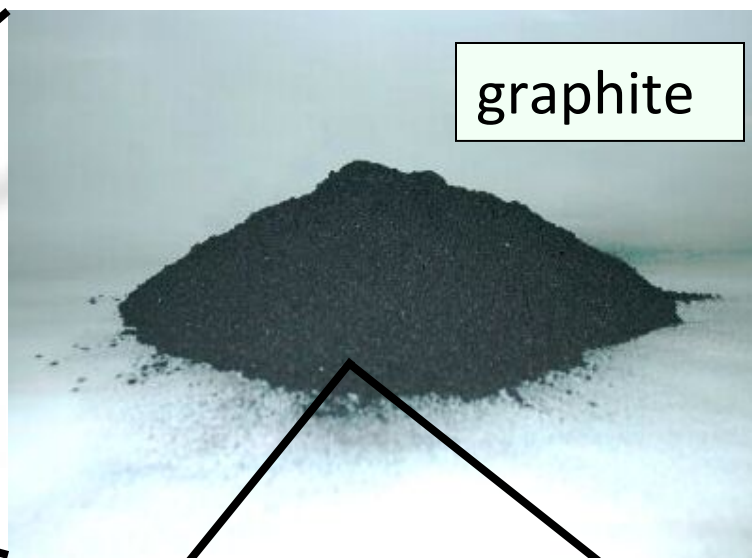
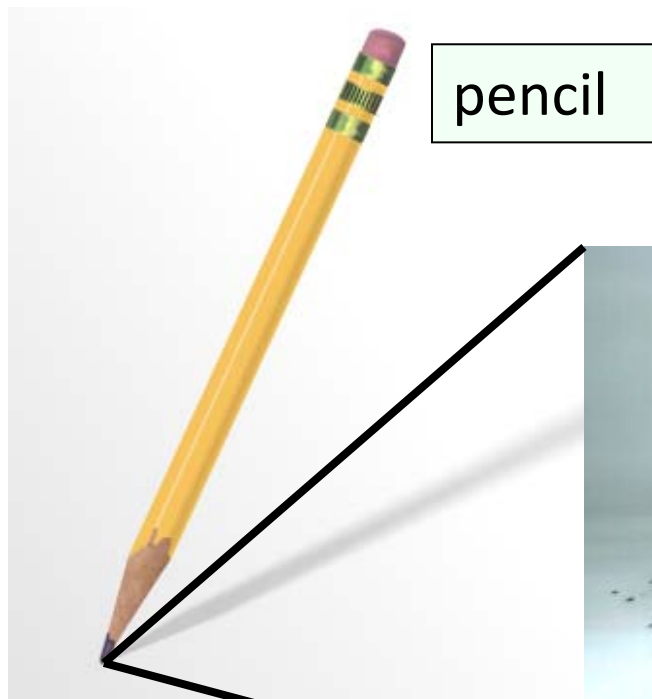


Efficient water filters

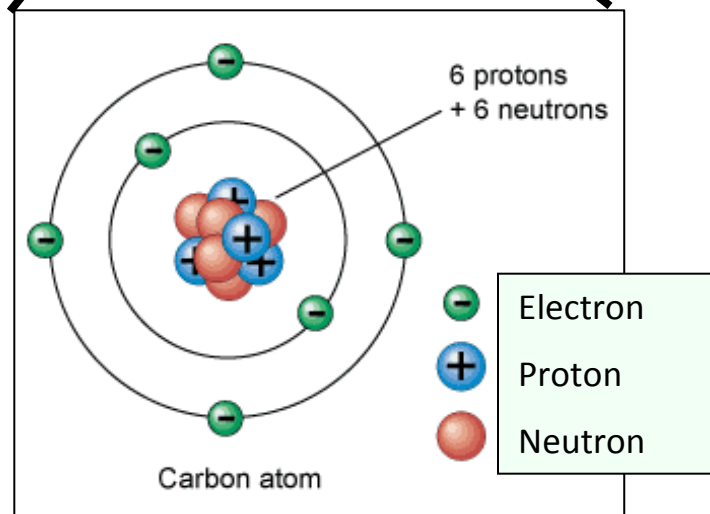
Discovery of Antimatter



What is matter made of?



carbon atom



Protons, neutrons and electrons are the building blocks for all the elements we know

PERIODIC TABLE OF THE ELEMENTS

<http://www.ktf-split.hr/periodni/en/>

PERIOD	GROUP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		IA	IIA	IIIB	IVB	VB	VIB	VII	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1		1.0079 H HYDROGEN																	2 4.0026 He HELIUM
2		3 6.941 Li LITHIUM	4 9.0122 Be BERYLLIUM											5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON
3		11 22.990 Na SODIUM	12 24.305 Mg MAGNESIUM											13 26.982 Al ALUMINIUM	14 28.086 Si SILICON	15 30.974 P PHOSPHORUS	16 32.065 S SULPHUR	17 35.453 Cl CHLORINE	18 39.948 Ar ARGON
4		19 39.098 K POTASSIUM	20 40.078 Ca CALCIUM	21 44.956 Sc SCANDIUM	22 47.867 Ti TITANIUM	23 50.942 V VANADIUM	24 51.996 Cr CHROMIUM	25 54.938 Mn MANGANESE	26 55.845 Fe IRON	27 58.933 Co COBALT	28 58.693 Ni NICKEL	29 63.546 Cu COPPER	30 65.39 Zn ZINC	31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.80 Kr KRYPTON
5		37 85.468 Rb RUBIDIUM	38 87.62 Sr STRONTIUM	39 88.906 Y YTTRIUM	40 91.224 Zr ZIRCONIUM	41 92.906 Nb NIOBIUM	42 95.94 Mo MOLYBDENUM	43 (98) Tc TECHNETIUM	44 101.07 Ru RUTHENIUM	45 102.91 Rh RHODIUM	46 106.42 Pd PALLADIUM	47 107.87 Ag SILVER	48 112.41 Cd CADMIUM	49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON
6		55 132.91 Cs CAESIUM	56 137.33 Ba BARIUM	57-71 La-Lu Lanthanide	72 178.49 Hf HAFNIUM	73 180.95 Ta TANTALUM	74 183.84 W TUNGSTEN	75 186.21 Re RHENIUM	76 190.23 Os OSMIUM	77 192.22 Ir IRIDIUM	78 195.08 Pt PLATINUM	79 196.97 Au GOLD	80 200.59 Hg MERCURY	81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.98 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON
7		87 (223) Fr FRANCIUM	88 (226) Ra RADIUM	89-103 Ac-Lr Actinide	104 (261) Rf RUTHERFORDIUM	105 (262) Db DUBNIUM	106 (266) Sg SEABORGIUM	107 (264) Bh BOHRRIUM	108 (277) Hs HASSIUM	109 (268) Mt MEITNERIUM	110 (281) Uun UNUNNIUM	111 (272) Uuu UNUNUNIUM	112 (285) Uub UNUNBIUM	114 (289) Uuq UNUNQUADIUM					

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)
Relative atomic mass is shown with five significant figures. For elements having no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.

However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@netlinx.com)

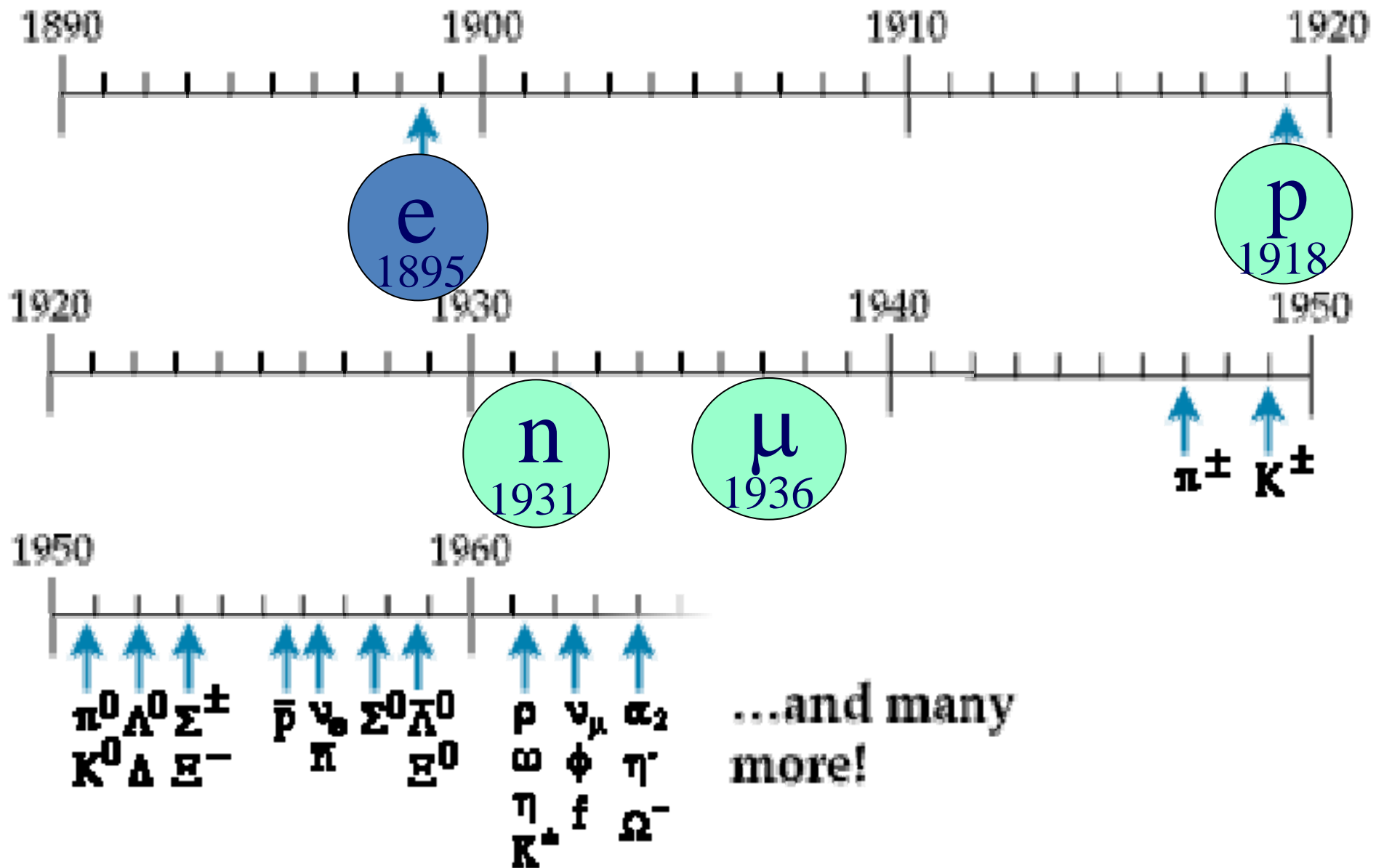
57 138.91 La LANTHANUM	58 140.12 Ce CERIUM	59 140.91 Pr PRASEODYMIUM	60 144.24 Nd NEODYMIUM	61 (145) Pm PROMETHIUM	62 150.36 Sm SAMARIUM	63 151.96 Eu EUROPIUM	64 157.25 Gd GADOLINIUM	65 158.93 Tb TERBIUM	66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.04 Yb YTTERIUM	71 174.97 Lu LUTETIUM
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89 (227) Ac ACTINIUM	90 232.04 Th THORIUM	91 231.04 Pa PROTACTINIUM	92 238.03 U URANIUM	93 (237) Np NEPTUNIUM	94 (244) Pu PLUTONIUM	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM
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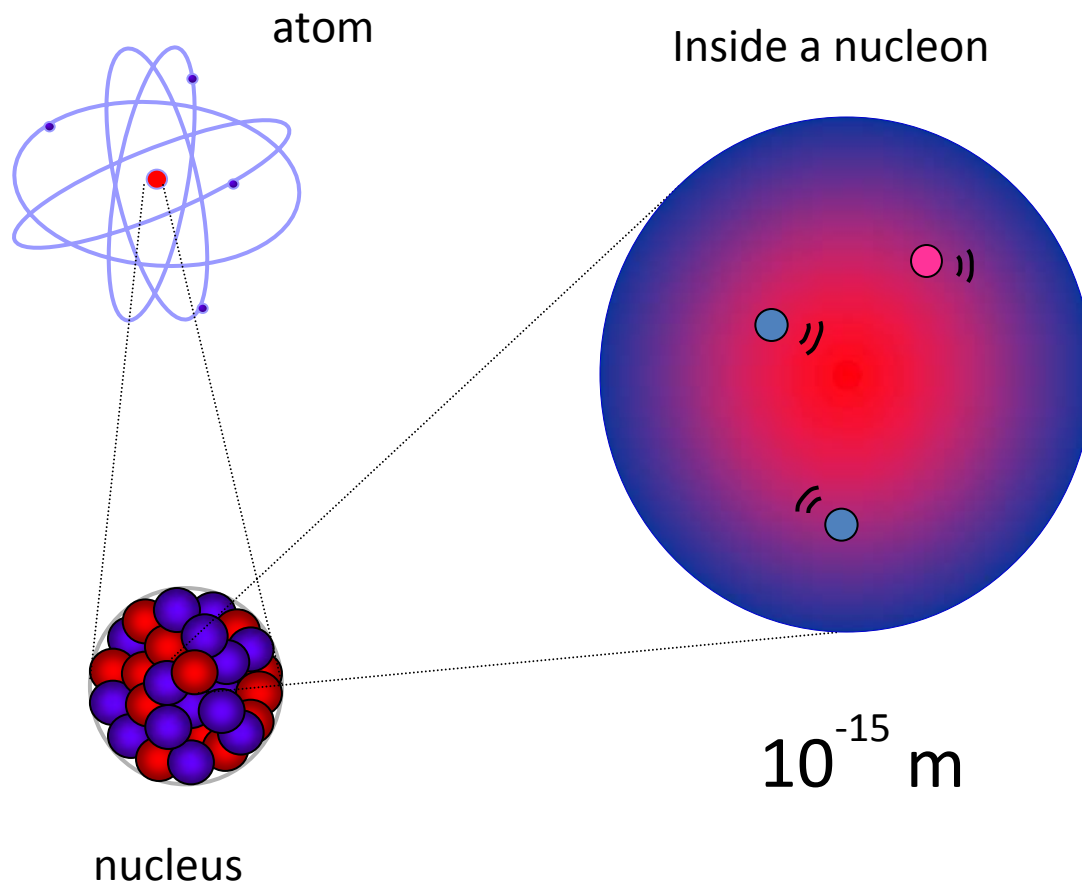
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For more information and downloads please visit ---> <http://www.periodni.com/en/download.html>

New particles are discovered



Is there more? The structure of the nucleus

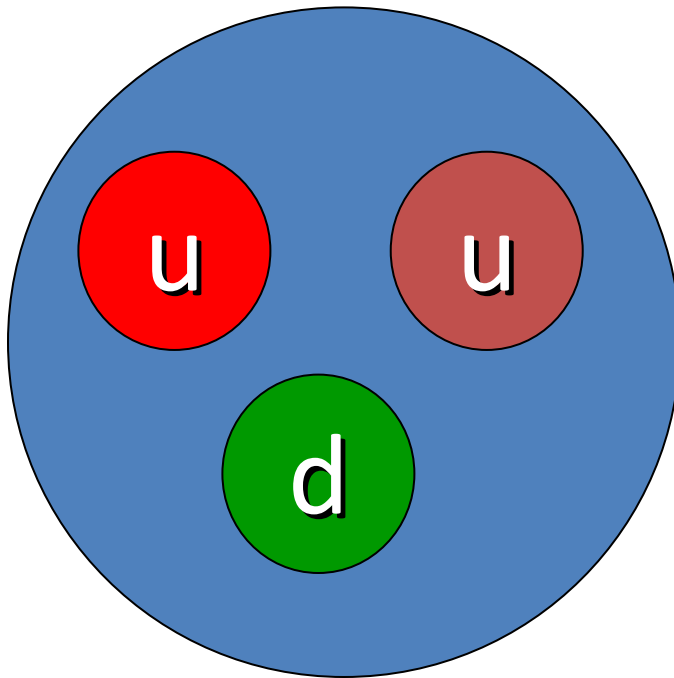


Neutrons and
protons contain
quarks

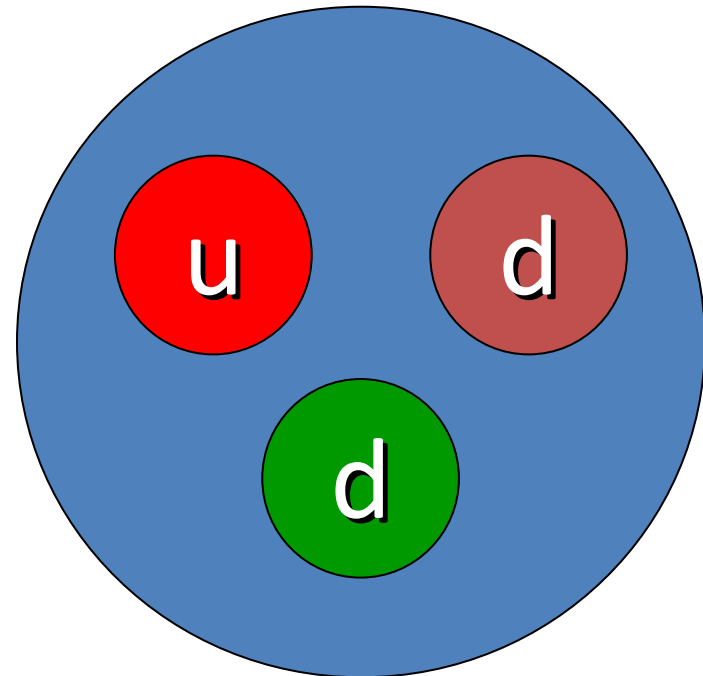
Protons and neutrons in the quark model

The quark hypothesis was tested at the Stanford Linear Accelerator Center (SLAC) in California, late 1960s

proton (charge +1)

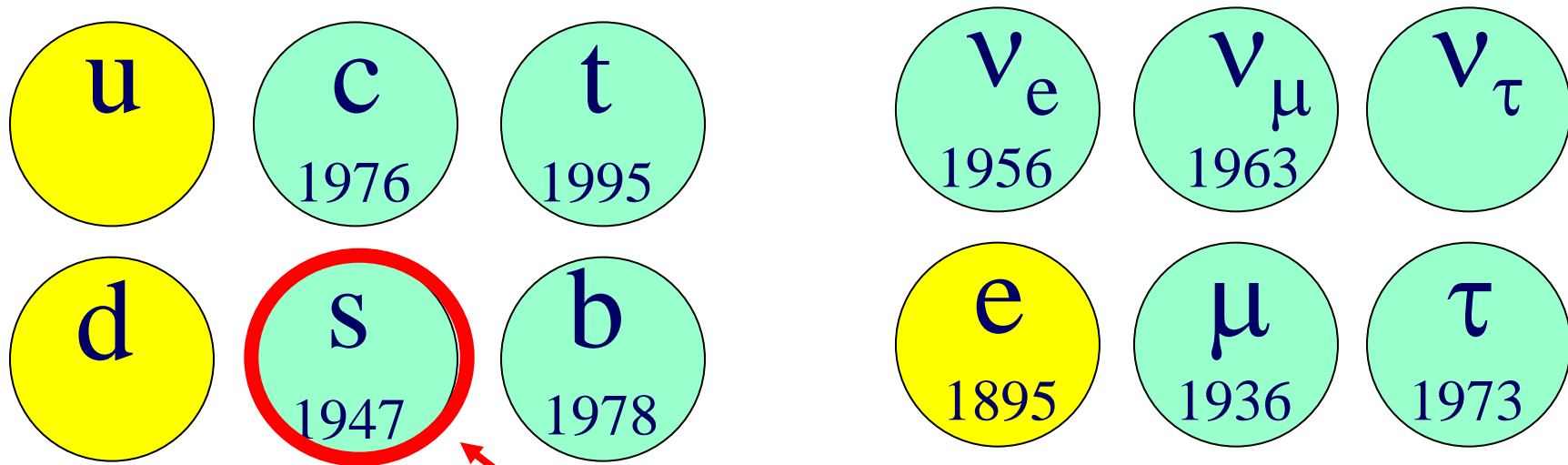


neutron (charge 0)



The zoo grows larger

We believe these to be the fundamental building blocks of matter



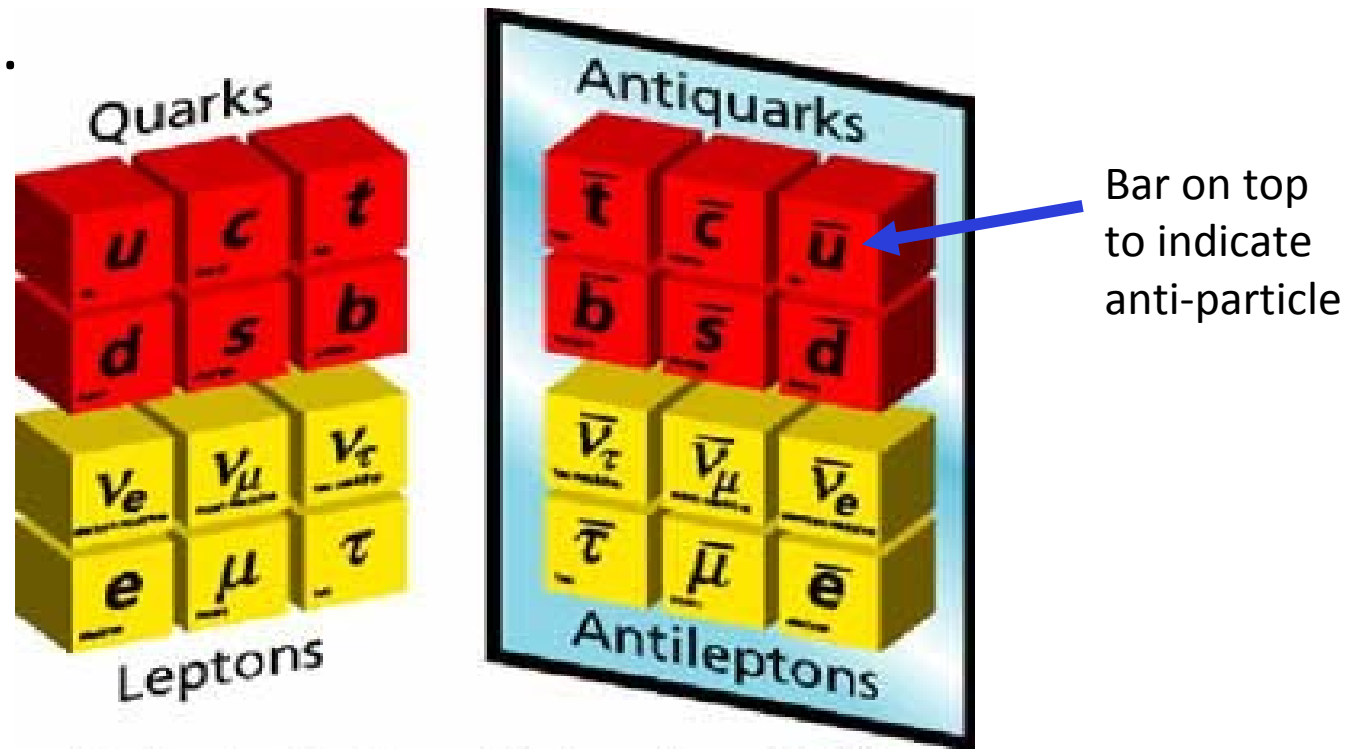
six quarks

six leptons

Maria's PhD

Is that all?

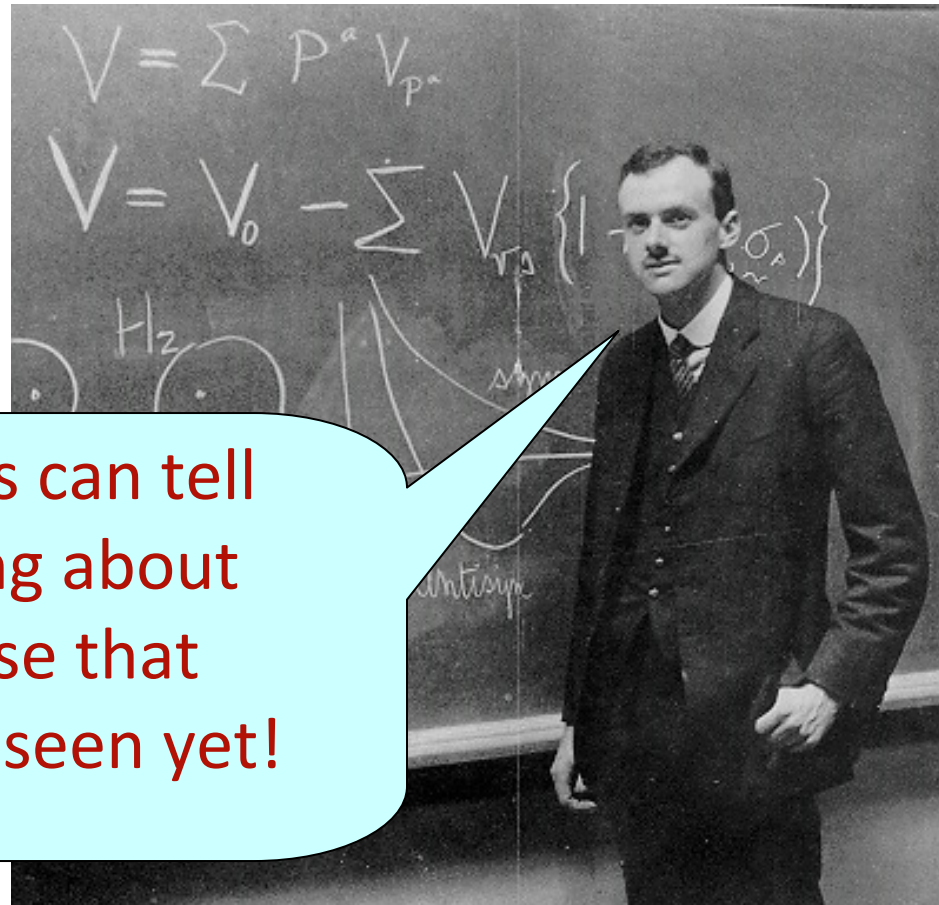
Actually...no.



- For every quark, there is a corresponding anti-quark
- For every lepton, there is a corresponding anti-lepton
- They look just like matter but have the opposite charge

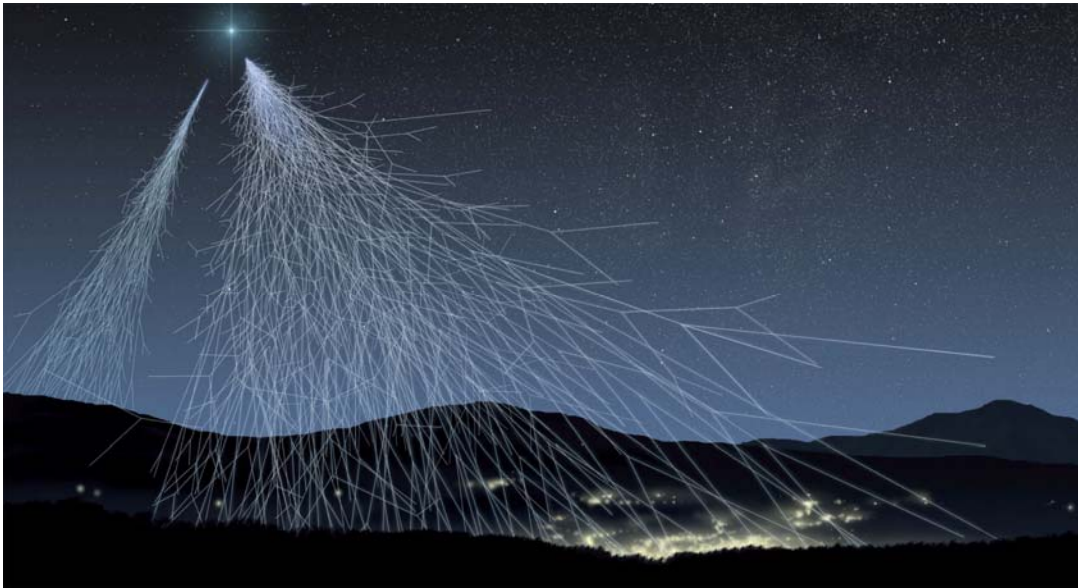
Prediction of antimatter

- In 1928 the young Paul Dirac mathematically predicted the existence of antimatter (the positron) when solving a quadratic equation.
- In 1932 Anderson discovered the positron predicted by Dirac.

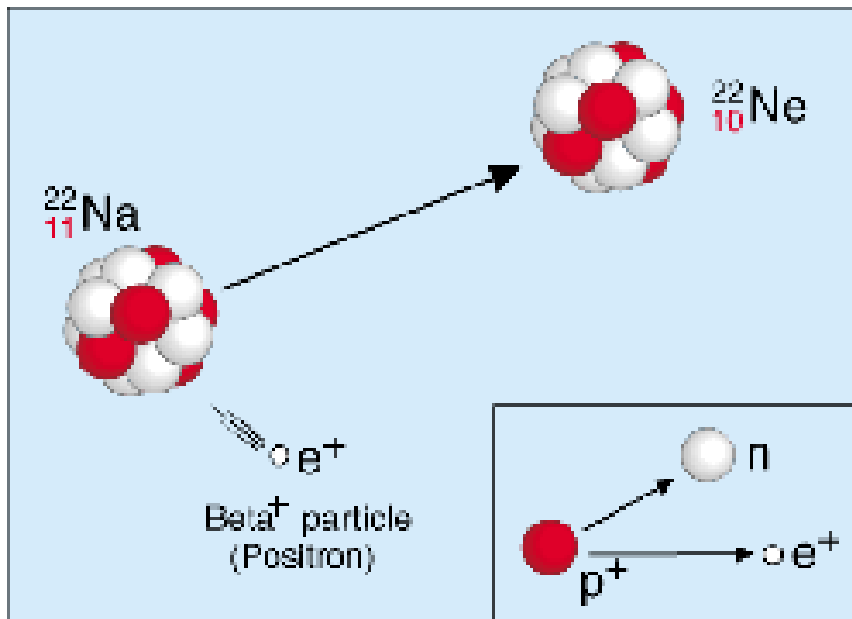


Mathematics can tell
us something about
our universe that
we have not seen yet!

Nature can make anti-particles



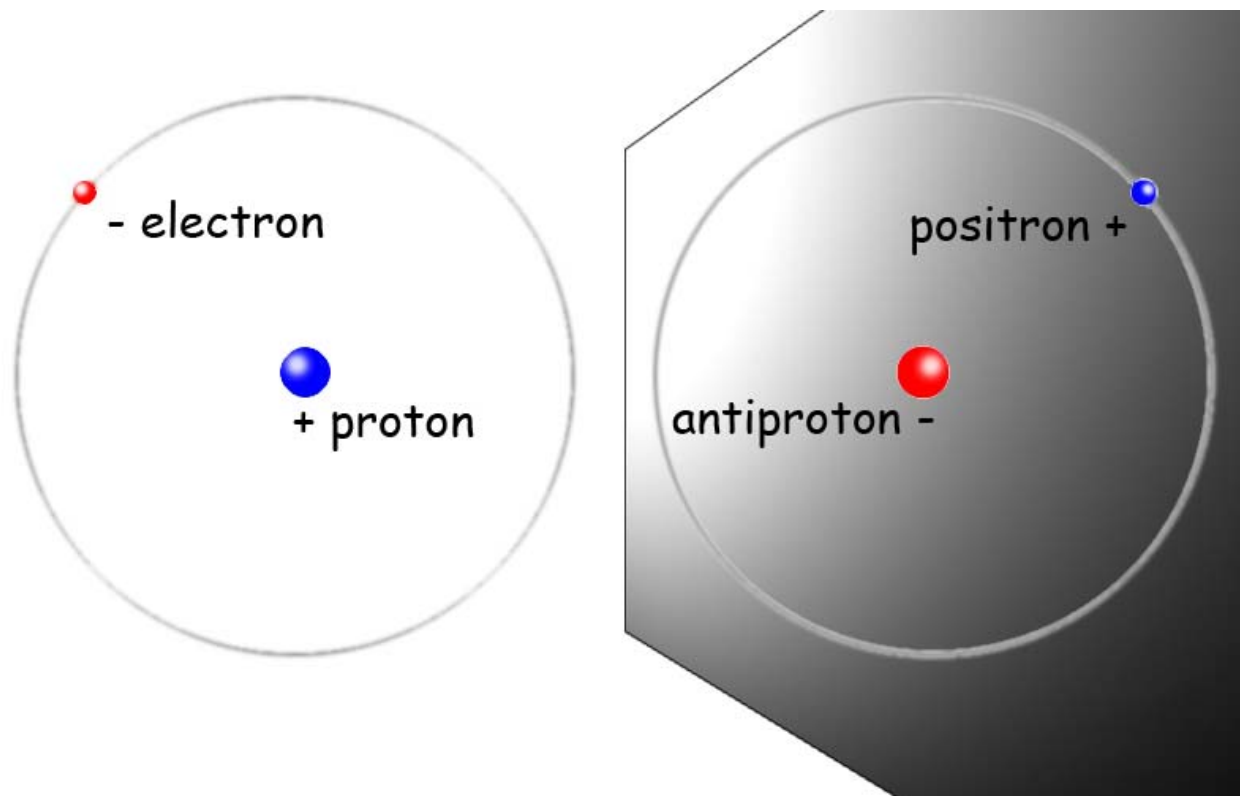
Cosmic rays are made up of many antiparticles



**Radioactive beta decay:
Sodium = Neon + e^+**

We can make anti-Hydrogen

- If you put a positron and an antiproton together you get a molecule of anti-hydrogen
- This is what they can make at CERN in Switzerland and at Fermilab in the USA.



An explosive relationship

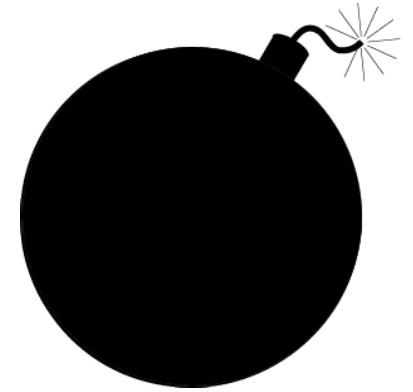
- When an antimatter particle touches a matter particle they are both wiped out in a flash of energy
- At CERN they can only keep positrons and antiprotons briefly in an elaborate magnetic trap



What can we do with anti-matter?

Can we make anti-matter bombs?

- There's no chance of making an antimatter bomb.
- It takes way more energy to make mere particles of the antimatter than you get out when it's annihilated with matter!



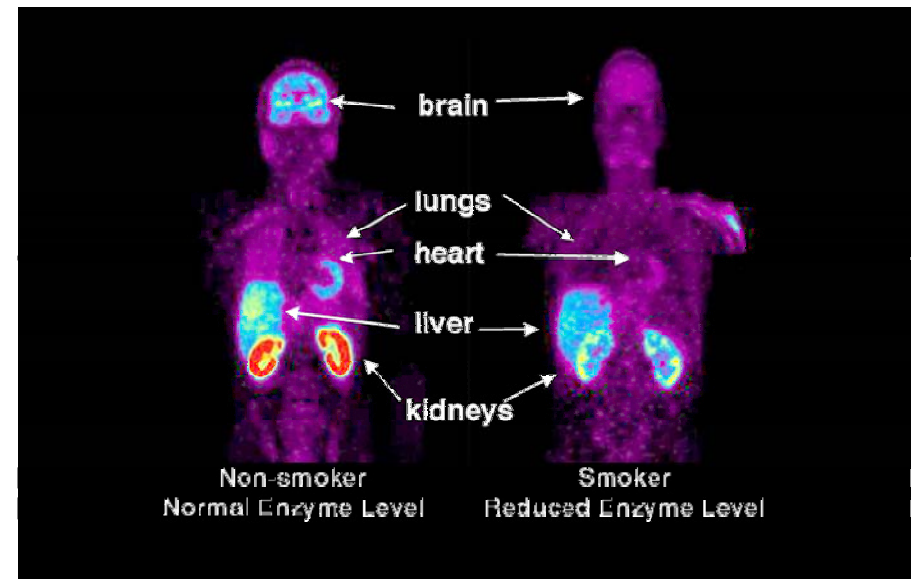
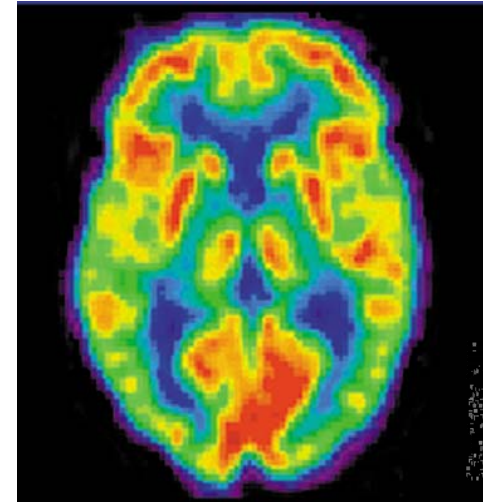
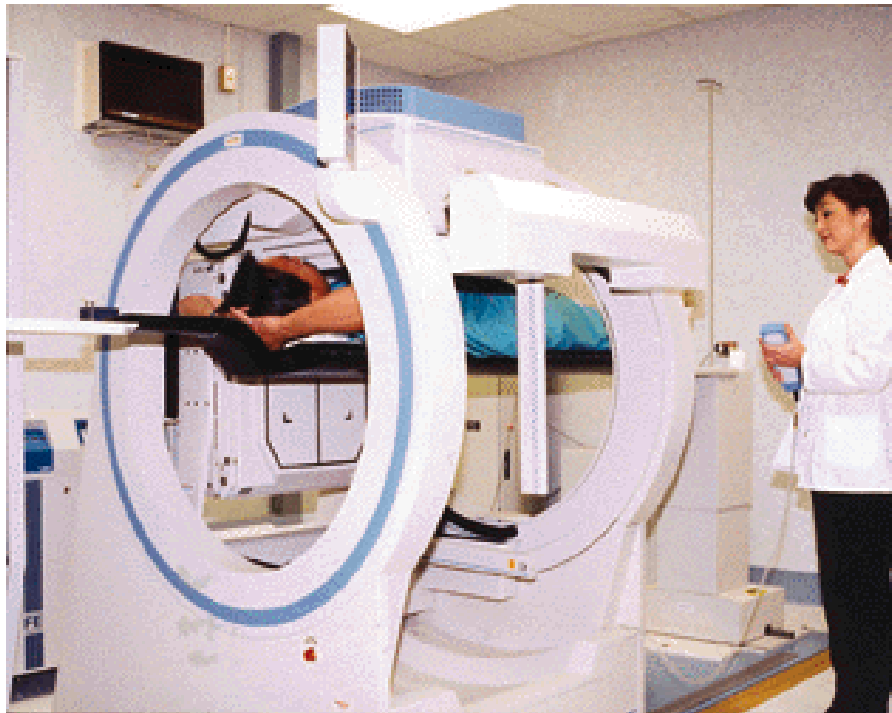
Can we use it for energy?

- Not really. In 10 years, CERN has made just about a billionth of a gram of antimatter
- Enough to power a light bulb for a few minutes
- More energy goes in than it is produced
- Maybe a new propulsion technique for spaceship...?



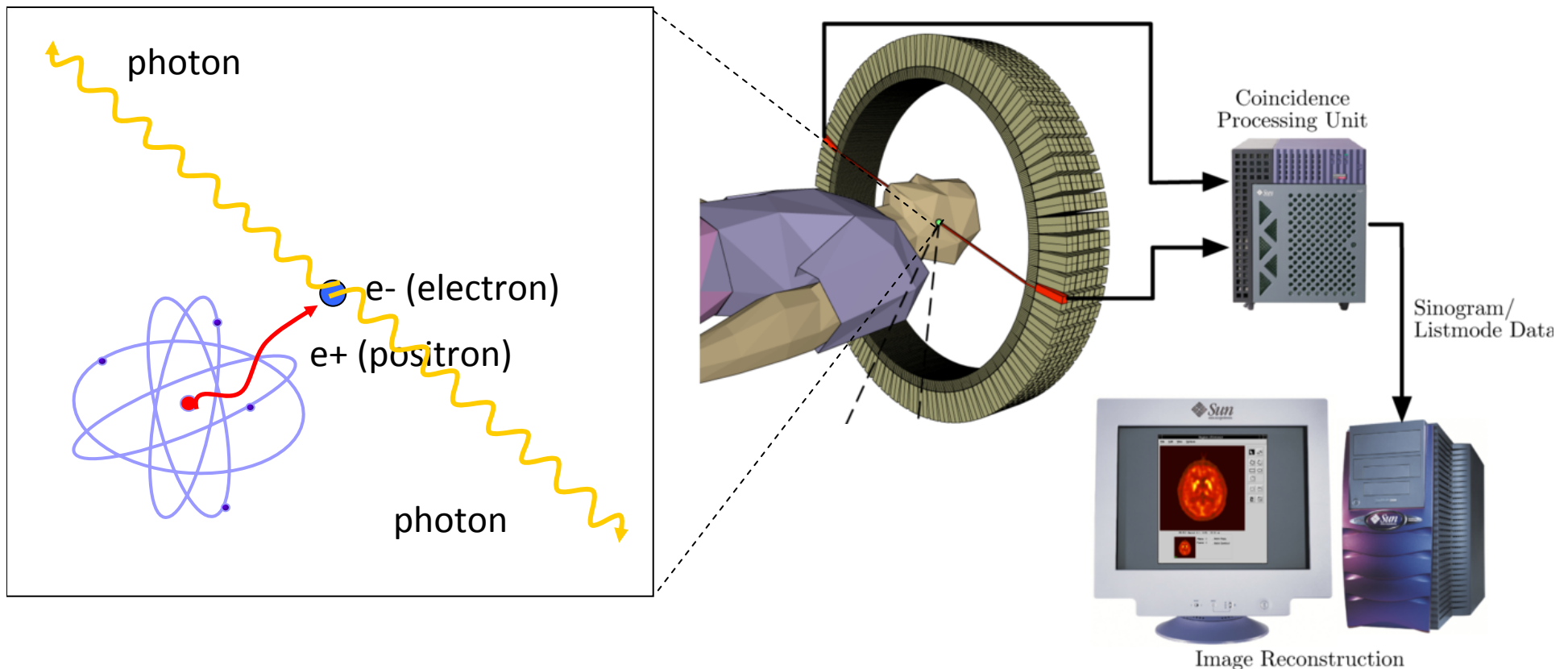
Antimatter is used in medicine

PET Scans (Positron Emission Tomography)



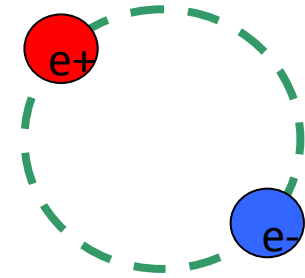
How does it work?

Positron emission tomography (PET) is a **nuclear medicine imaging** technique which produces a 3D image of functional processes in the body.



What else can we do with positrons?

We can bind an electron to a positron to make *positronium* (UCR has a leading research team)

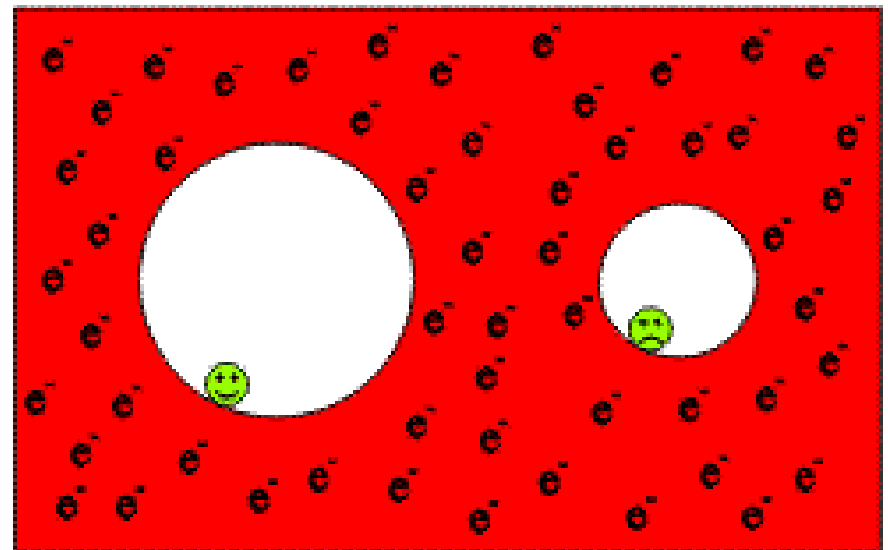


Applications of positronium include:

- Intense Gamma-Ray Laser
- Positronium Annihilation Lifetime Spectroscopy to probe the microscopic structures of materials
- *[Your application here]*



This is where I spend some of my time now...



Let's do some thinking

- Anti-matter exists: nature can make it and we can make it too.
- For each matter particle we create, an anti-matter particle is created too.
- But, there is very little natural anti-matter in the universe...
- Where is all the anti-matter?
- Does anti-matter behaves like matter?
- Can we use anti-matter?



Matter, Antimatter, and the Universe

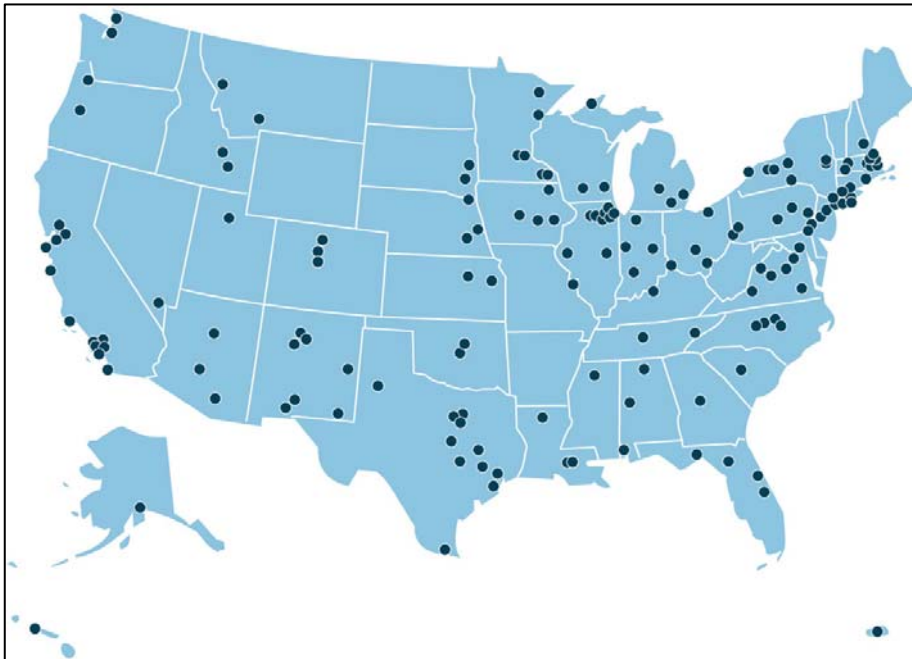
- At the beginning of the Universe, 15 billion years ago, the Big Bang produced equal amounts of matter and anti-matter
- Everything should have annihilated. Instead...
- Where did all the anti-matter go?



*In the early universe, for every billion ordinary particles annihilating with antimatter,
one was left standing...*

Searching for Answers

- Particle physics laboratories around the world



- At universities and laboratories across the United States

Summary:

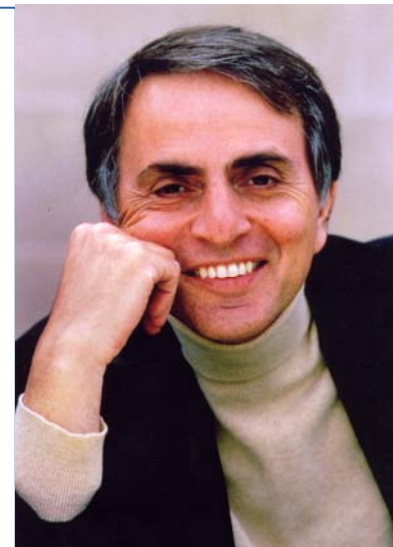
what is important to know?

Mathematical Practices

1. Make sense of problems and persevere in solving them;
2. Reason abstractly and quantitatively;
3. Model with mathematics;
4. Look for and express regularity in repeated reasoning.

The truth may be puzzling. It may be counterintuitive. It may contradict deeply held prejudices. It may not be consonant with what we desperately want to be true.

But our preferences do not determine what's true. We have a method, and that method helps us to reach not absolute truth, only asymptotic approaches to the truth — never there, just closer and closer, always finding vast new oceans of undiscovered possibilities.



Carl Sagan